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Bunch Arrival Time Measurement System Test for SHINE

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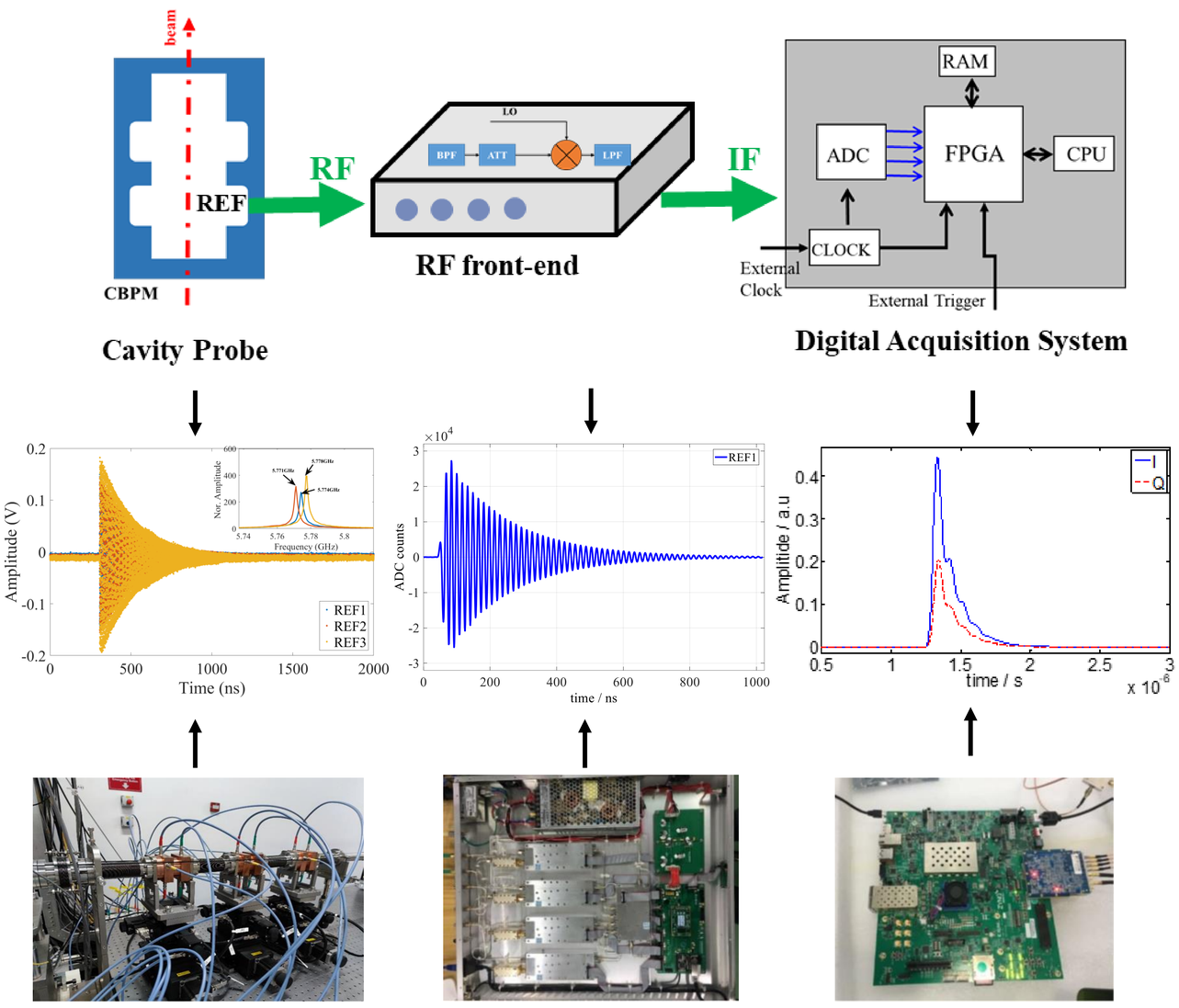
Abstract

To achieve high-precision synchronization between electron bunches and seeded lasers, a femtosecond resolution bunch arrival time measurement system (BAM) is required for SHINE (Shanghai High repetition rate XFEL aNd Extreme light facility). The BAM system is com-posed of three modules. Bunch signal from the cavity probe is mixed with a reference signal from the facility synchronization clock in the RF front-end. Then, the generated IF signal is collected by the digital acquisition system. In the pre-research stage, three sets of cavity probes with different frequencies and three sets of analog front-ends with different schemes were performed. However, only cavity probes with the attenuation time constant of 200 ns were installed on the beam experimental test platform. Each sub-module of the BAM system will be tested and evaluated, and the system will be used to measure bunch arrival time and bunch flight time. The first beam experimental results will be presented in this paper.

System structure of bunch arrival time measurement system



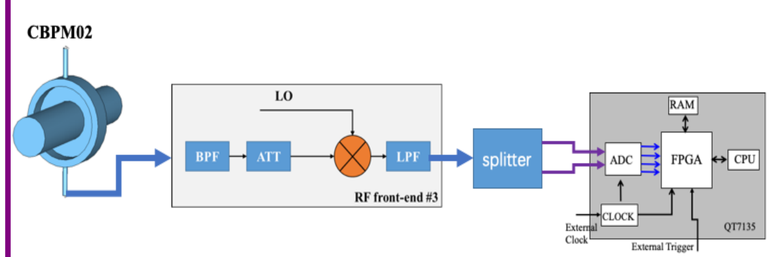
Motivation:

- Test the performance of each sub-module
- Measure the bunch arrival time and flight time with the prototype
- Guide the direction of optimization

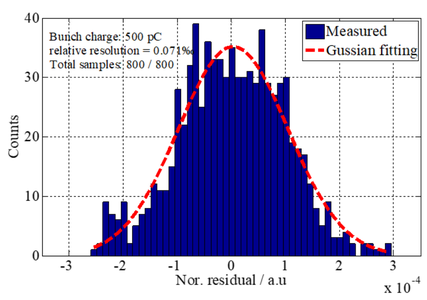
Three modules	Characteristics
Cavity probe	**Function:** *coupling out beam information (including charge, beam arrival time and position)* **Parameters:** *three sets of cavity probes with different frequencies designed, but only CBPM-200ns was installed* CBPM200-02 REF cold test results: 5.773GHz, BW 1.49MHz, Qload 3877, decay time 214ns (S. S. Cao et al., "Design and Test of CBPM Prototypes for SHINE", IBIC'20)
RF front-end	**Function:** *filter, amplify, and down-convert the RF signal from the cavity probe to an IF signal* **Parameters:** *three sets of analog front-ends with different design schemes performed, the noise floor of prototype #3 is the lowest* prototype #3 REF: lab testing (std~31.5), beam testing (std~13.2) (Y.M. Zhou et al., "Prototype Design of Bunch Arrival Time Measurement System Based on Cavity Monitor for SHINE", IBIC'20; J. Chen et al., "Development of the Prototype of the Cavity BPM System for SHINE", IPAC'21)
Digital Acquisition System	**Function:** *Real-time online data processing in FPGA to extract beam position information and phase information* **Parameters:** *technical requirements: Sampling rate>500MSPS, BW>60MHz, ENOB>9bits* Beam experiment use: QT7135 developed by Queentest company (1GSPS, 1.2GHz, 12bits)

Experimental schemes and measurement results

#1: Evaluating the digitizer (QT7135)



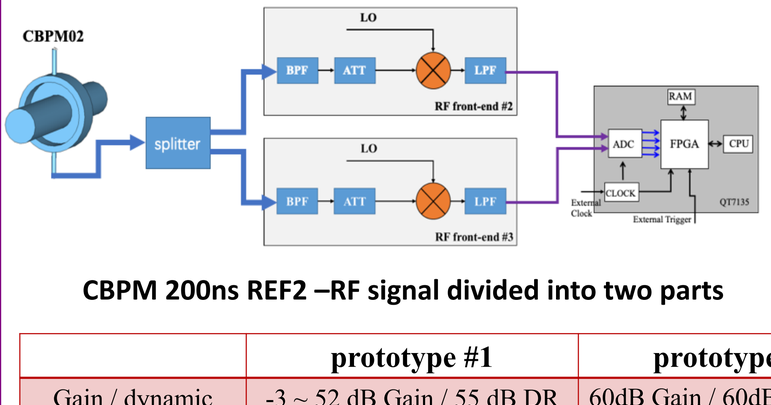
RF front-end prototype#3
-REF2 IF signal divided into two parts



Evaluate signal amplitude extraction uncertainty

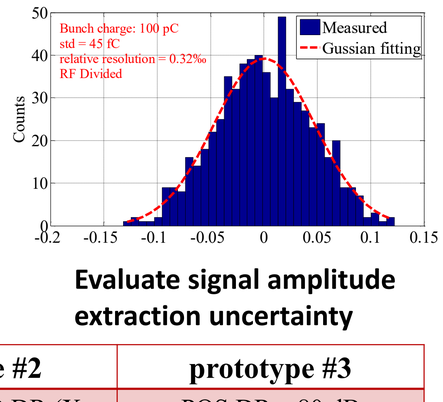
Test conditions	Bunch charge 500 pC			
DAQ	SP ADQ14AC-4C	DAQ by USTC	QT7135	QT7126
Parameters	14 bit 1004.8 MHz Sampling rate Range: ±0.95 V	16 bit 833 MHz Sampling rate Range± 1V	16 bit 952 MHz Sampling rate Range± 1V	12 bit 2380 MHz Sampling rate Range~ ± 0.6 V （8dBm peak）
Relative extraction uncertainty	0.116 ‰	0.15 ‰	0.071 ‰	0.33 ‰
Conclusion	QT7135 > SP ADQ 14AC-4C > DAQ by USTC > QT7126			

#2: Evaluating the RF front-end



CBPM 200ns REF2 –RF signal divided into two parts

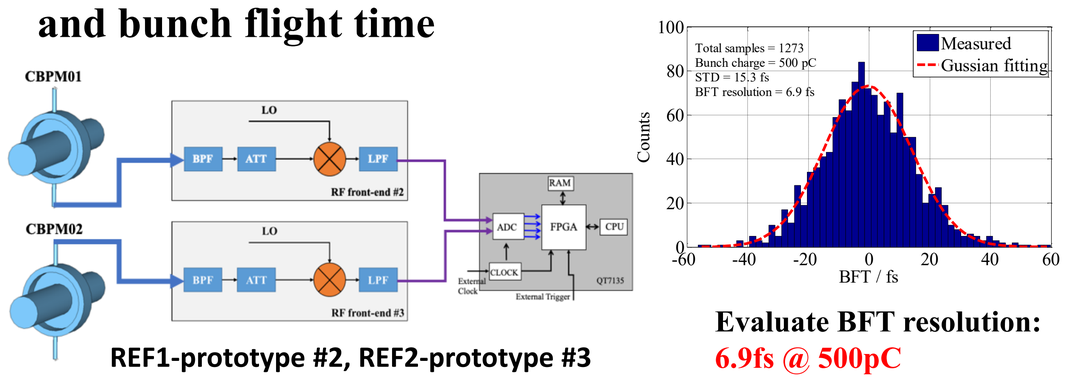
Prototype #2 & Prototype #3



Evaluate signal amplitude extraction uncertainty

	prototype #1	prototype #2	prototype #3
Gain / dynamic range:	-3 ~ 52 dB Gain / 55 dB DR (X、Y、 Z) -22 ~ 3 dB Gain / 25 dB DR (REF)	60dB Gain / 60dB DR (X、Y、Z) 19dB Gain / 40dB DR (REF)	POS DR：80 dB REF DR：50 dB
Adjustable gain	1dB / step	1dB / step	0.25dB / step
Crosstalk	< -61 dB	< -62 dB	< -66 dB
Noise Figure	REF：0.059 %	REF：0.056 %	REF：0.032 %
Local oscillator phase noise	~ 36 fs (476MHz clock)	~ 20 fs (476MHz clock)	~ 7 fs rms (5712MHz clock)

#3: Measuring the bunch arrival time and bunch flight time



REF1-prototype #2, REF2-prototype #3

Evaluate BFT resolution:
6.9fs @ 500pC

Conclusion

- Successfully construct a BAM system
- Complete the test of each sub-module
- Measure the bunch arrival time and flight time, BFT resolution reached 6.9fs @ 500pC

SHINE

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